Co-modeling: An Agent-Based Approach to Support the Coupling of Heterogeneous Models

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Abstract. Coupling models is becoming more and more important in the fields where modeling relies on interdisciplinary collaboration. This in particular the case in modeling complex systems which often require to either integrate different models at different spatial and temporal scales or to compare their outcomes. The goal of this research is to develop an original agent-based approach to support the coupling heterogeneous models. The architecture that we have designed is implemented in the GAMA modeling and simulation platform [6]. The benefits of our approach is to support coupling and combining various models of heterogeneous types (agent-based, equation-based, cellular automata) in a flexible and explicit way. It also support the dynamic execution of the models which are supposed to be combined during experiments. We illustrate its use and powerfulness to solve existing problems of coupling between an agent-based model, equation-based model and GIS based model. The outcomes of the simulation of these three models show results compatible with the data observed in reality and demonstrate the interest of our approach for building large, multi-disciplinary models.

Keywords: Models Coupling · Agent-based modeling · Simulation platforms · Land-use change dynamics

1 Introduction

Coupling, anchoring and composing models is more and more common, especially in the field of sustainable development, where researchers tend to work in multidisciplinary setups. Requirements to do so can come from the necessity to integrate different models (for instance, urban and climate models), to compare the outcomes of models used in decision-making processes, to couple models of the same phenomena at different spatial and temporal scales, and so on. Moreover, the questions of the end-users, for which models are initially designed, have become more complex and less focused, forcing modelers to anticipate probable changes in the structure of the models, or to design models in such a way that they can be incrementally modified or experimented in unexpected ways.

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Various solutions have been proposed in the latest years, but they are mostly oriented towards technical approaches to the operational coupling of models (HLA [2], DEVS [19], FMI [1]]), leaving aside the semantic problem of their static or dynamic composition. In particular, there is no way one can provide, let alone revise and reuse, a description of their composition, such as, for instance, the spatial and temporal scales of the models involved, their transfer functions, how they are supposed to be combined during experiments, etc.

In this paper we propose a new approach for the coupling of heterogeneous model developed in a simulation platform Gama. This approaches is tested on a concrete case study of the land use change which is defined every 5 years through a specific methodology: this one is based a land use evaluation according to several environmental (water quantity and quantity, soil type) and socio-economical factors.

In Section 2, we present the definition, problem of coupling model and the existing approaches. In Section 3 we describe our proposed approaches: co-modeling, and how it has been implemented in the GAMA simulation platform. Section 4 provides some results obtained by simulating the coupled model and describes in details the experiments that we have conducted. Finally, Section 5 concludes our ongoing work.

2 Models Coupling

2.1 Definition

In general, the terminology of coupling between models is used when modeler makes some interactions between at least two models which have ability to operate independently [4]. This approaching of coupling can be found when modeler wants to do research on the heterogeneous system with many levels of details and the best approaching model of that system is an association of different existing models. It also occurs when modeler wants to answer a complex question with different existent components that have been made in special objectives. For instance, the question of climate changes (as the general one in ecologies) is a clear example of the necessity to couple different domains or researches from multidisciplinary with different level of spatial and times scales.

A model referencing a heterogeneous systems, is called heterogeneous model, include multiple components, each component is a model or smaller systems, which can operate independently of each other. The coupling of heterogeneous models [8] can be considered as several meaning: it is the connections, the links, and the anchors between models with models. It shows how the models are integrated with each others, how they can interact in coupling context. Models can be coupled themselves with the others in a certain order of space or time to be a system corresponding with the scales in heterogeneous system.

2.2 Type of Coupling

In [7], the authors classify the coupling based on the principle of coupling as following:

- Methods based on a coupling factor (space, time event) or a common element models is identified to the coupling operation. For example the specification language DEVS (Discrete Event System Specification) [19], the DS model [3].
- The methods based on an intermediqate using an interface for coupling the various models. In this category of approaches include the Osiris model [4] for the UrbanSim model[17], the HLA [2] model.
- Methods based on integration where the models are built, modified and adapted to each other to build a new model.

In [4], the authors list the coupling approaches by degree of the coupling:

- The coupling which is based on the establishment of data transmission, is also called a weak coupling, this approach of coupling depends on a solution of technical infrastructure of simulator, if these facilities can support the simulation of models from different platforms.
- The strong coupling describes the coupling between behaviors of models, for the integration between each of them. This type of coupling is often based on the same platform, which provides the capability to import or re-implement one or many parts of existent models.

We choose to categorize the coupling in two type: (1) The coupling which is based on the establishment of data transmission or exchangement values, is also called weak (loosely) coupling. This approach of coupling depends on a solution of technical infrastructure of simulator, if these facilities can support the simulation of models from different platform. This type of coupling contains a set of common data exchange protocol. (2) The strong coupling describes the coupling between behaviors of models.

2.3 Importance of Coupling

Coupling models is a high priority approach which seeks to enhance knowledge and reuse previously validated models, to expect at the same time a lower risk of error and a faster construction of simulation models. Climate forecast, prediction of environmental risks or simulation of urban mechanisms are the relevant examples. For example, the zoning process is defined at 4 administrative levels: National, Provinces, Districts and Communes. Based on this zoning process, a land use planning policy is defined every 5 years through a specific methodology: this one is based a land use evaluation according to several environmental (water quantity and quantity, soil type) and socio-economical factors. However, the land use planning is rarely followed by farmers because of: (1) modifications of the natural conditions, (2) changements in the farmers socio-economic situation or the fact that farmers may prefer to follow other farmers when making their decision of land use change. This scenario leads to the need of coupling models to test hypotheses on the main factors influencing farmer's decisions who taking into account external (physical or economic) factors. The model would be very complex as it touches on many fields providing a lot of factors related to the behaviors of the farmer, the economic and the natural conditions. It is not easy to combine various factors coming from different models.

2.4 Problems

In this paragraph, we generally introduce the existing problems of the coupling activity.

Different Formalism of Coupling. Because coupling models often take place when the modeling carried out with more and more models from many different fields that each one has a particular modeling formalism. Thus, modeler has been lead to the problem of diverting the formalism of coupling models. Nowadays, scientific models usually base on three formalism: model base on differential equation, model base on automata cellular, model base on agent. The three formalism are different naturally in the way that they describe the model and it is the root cause why they have a big difficulty to reuse all in one context.

Spatial and Temporal Scales. While couple models, modeler usually encounter with the needs to change the spatial and temporal level of an object or components of model. This change benefit the diverse representation from one model to other considering their discipline.

Facilitation the Manipulation of Coupling. Most of the current solutions proposed dont support an approach to ease the description of coupling between models. It leaving aside the semantic problem of dynamic composition.

2.5 Existing Approaches

There are three existing popular coupling formalism: High-Level Architecture (HLA) [2] and Discrete Event Systems (DEVS) [19], Functional Mockup Interface [1]).

HLA uses most in humans training to perform tasks and analysis of scenarios in a simulated world. HLA integration the mechanism for the synchronization of simulators whenever they exchange data. The principle of HLA is consider that simulators are assemblies to the Federation. An interface RTI (Runtime Infrastructure) assures the synchronization of exchange between the Federation. HLA is defined by three core elements: the template object model (contains HLA Federation Object Model and HLA Simulation Object Model), the interface specification with Runtime Infrastructure, and HLA rules.

DEVS is a formalism proposed to model discrete event systems with two type of models: model atomic is considered as sub model with contribute parameters (the set of input, output events, sequential states; the time advance, the external/internal transition function and the output function. It helps modeler to specify their models events, set of states, internal and external transition, inputs and outputs), and coupled model which specify by three main set of: atomic models to be coupled, translation function between models, influences between models. The interaction assured by the ports, input and output, which are favorites the modularity.

FMI is an independent approach for model exchange that is support black box model exchange. This standard has been developed to meet the requirements of standardization, availability, easy-of-use, adoption, accompanying documentation and maturity of such an interface. This standard is a promising candidate to become the industrial standard and cross-company collaboration, but it is not suitable too much with white box modeling of the complex system with one modeling language that is not suitable for all requirements in different domains. This approach offers the possibility for deep system understanding by equation-based, object-oriented modeling and symbolic manipulation.

Beside these three common standards, such works have often implemented their own coupling method of spatial, temporal and data on a specific modeling platform. Many researches have been done to couple the models of complex system in multi-discipline: coupling among model different domain (urban - travel [10], environment and pelagic resources [18], community land model to the regional climate [14]). Other researches couple multi models in same domain but in different objective, to show if these objectives represent an important factor that modify or improve in the simulation results and evaluate them [11]. They exchange the data in phase of executions in an order temporal simultaneous one by one or parallel, i.e., in [9] the coupling is called “coupler” who exchange data input and output between models scales. Coupling also has been done by different modeling approaches: coupling hydrodynamic model and individual-based models [12], coupling multi-agent model and GIS [8] [13], coupling of physical models and social models multi-modeling [5].

All these approaches provide mechanisms that allow interaction between several models but they still have following disadvantages:

- In general, these approaches are not very generic and seem to be very difficult to be re-implemented in different domains and contexts.
- There are no consideration of the differences in spatial and temporal scales.
- They do not support to couple the case of heterogeneous models between mathematician, informatics, GIS

3 Co-modeling

We present in this section the methodology we propose to couple multiple models. Then, it has been implemented in the GAMA agent-based modeling and simulation platform [6].

3.1 Conceptual Proposal

We propose to address the problem identified in II.C. with the modeling and simulating of the “co-model” as a contraction of “coupling of models” and "composing of models". The central claim of our approach will be considered a "co-model" as a model, and more specifically an agent-based model, in which the agents wrap one or several instances of the models to couple, with their own life-cycle, operations, collaborations, conflict resolution mechanisms, etc. which will draw from the numerous works already published on multi-agent systems.

In this perspective, a co-model will be a model that captures and represents a particular collaboration between these micro-models, which can be based on existing collaboration schemes between experts, or any other organisation of their contributions. Conversely, this work will allow to consider regular multi-agent based models as very specific implementations of co-models, where agents only wrap models of individuals. Our approaches challenge the first problem of coupling model, by considering agents as models, the different modeling formalisms could be considered as behaviors of agents. Then, it solve the second problem of spatial and temporal scales by inherit the rich existing researches on these difference level of scaling, thus the proposal did not, itself, propose the concrete solution. The inheriting from agent based modeling help modeler to easily manipulate the description of coupling with the declaration behaviors and attributes interaction between agents which are, in fact, models.

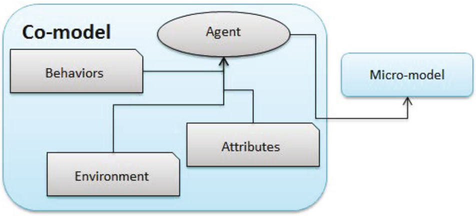

Fig. 1. Co-model extend the concept of agent-based modeling formalism

The figure 1 represent our propose: a comodels agent (in rose) associate with its attributes, behaviors and environment as normal agent, then we attache an concept micro-model to the agent. The agent, now, known theirs micro-models and can easily couple, access, integrate and control them dynamically.

3.2 Computer Implementation

To further clarify the co-modeling methodology, our enrichment enabled GAMA modeling language (GAML) to support the modeler in the development of coupling agent-based models.

We exploit the current meta-model of GAMA in Figure 2. It represents a diagram with three parts: meta-model, model and simulation. The meta-model part describes the meta-model concept of a agent based model in GAMA. These concepts of meta-model use in the model part to specify an agent-based model. The simulation part shows an example of a simulation initialized from the model. The current agent-based modeling platforms rely on a meta-model with the following principal concepts: Agent, Environment, Scheduler, Spatial scale and temporal scale. Agent represents the concept of agent in the model, which also defines a level of organization. Environment support modeling the environment in which agents are situated, i.e., the spatial scale. Scheduler schedules the execution of agents during the simulation, defined the temporal scale. Spatial and temporal scale concepts help modeler to define the spatial scale which is an area that agents can be situated, and temporal scale which defines how agents are scheduled in the simulation. This meta-model is missing a part of representing and manipulating the co-model of our approaches.

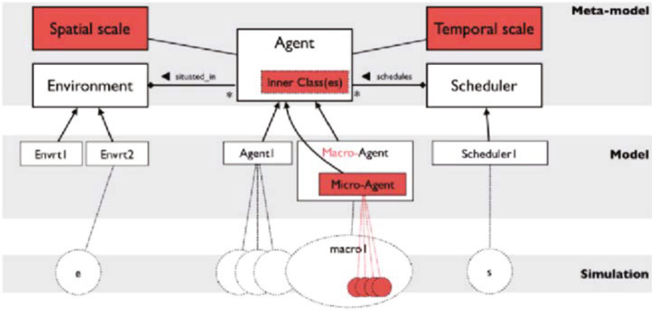

Fig. 2. A simplified meta-model of agent-based modeling platforms

To support the development of coupling model in agent based, we propose an extension of the current meta-model described in [16]. We thus introduce new concepts to do coupling operation. The new concepts micro-model represented as classes in the extended meta-model Figure 3 give an answer to the first two modelers requirement : Entities may define different levels of organization related to specific agents which create the instant the micro-models s experiment. These levels of organization may be hierarchical. The micro-model concepts, attached to Agent, offer the modeler the possibility to define the coupling model for each type of agent. It defines the models on which agents can access and control their schedule in the simulation, i.e., their scheduling frequency and order. These two concepts make the meta-model capable of satisfying the first requirement. Thanks to this concept, the modeler can declare an model as micro-model inside a specific Agent type which can be a normal Agent or the Agent World. The agent World is the top-level agent which is the instant of current model. An instance of the outer Agent type is called co-model while an instance of the inner Agent type is called micro-model. A co-model always maintains a reference to its micro-model and vice versa, the micro-model also know their container, co-model. This concept thus facilitates the modeling of hierarchical organization of levels and the coupling between levels, i.e., the modeling of interaction and data exchanges between levels.

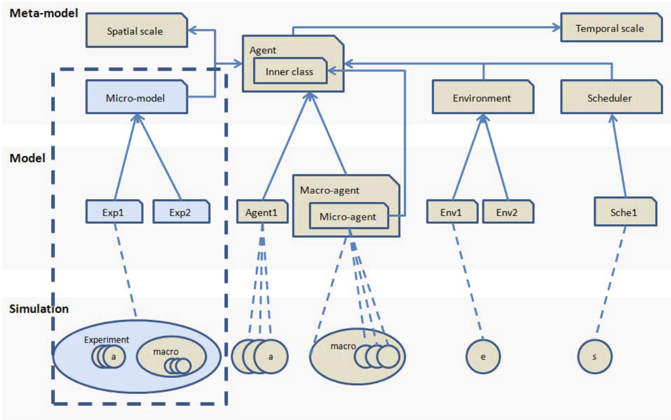

Fig. 3. Extend a simplified version meta-model of current agent-based modeling platforms to support coupling models (changes are in left dot-rectangle)

With our alter on the current meta-model, a co-model in GAMA is represented as model in GAML, which wrap several micro-models. This wrapping is called an importation. In side of current form of importation, all the declarations of the model(s) imported will be merged with those of the current model (in the order with which the import statements are declared, i.e. the latest definitions of global attributes or behaviors superseding the previous ones), we give its an model-identifier to precise the imported model are a micro-model. The co-model is implemented in GAMA with three phases: importation, instantiation and execution. These phases are not presented in the meta-model for the sake of simplicity, but it is controlled by the simulation process of GAMA. A species can thus contain several micro-model representing different coupling that agents of the species can execute. They are executed when the corresponding agents are scheduled by the scheduler. We present these three phase with demonstration by using the three model in figure 4. Model product market gives the values of the products. Model environments contains characteristics and dynamics of soil, water and flooding plots. Model cognitive with agents farmers choose among crops in neighbors that considers economic conditions and their culture.

Importation. This phase is extended from the current type of importation. Normally, the importation will merge all composition of imported models into the main model. We have modify it to accept an identifier of each micro-model importation. This identifier uses as alias name in which modeler decide to reuse the same micro-model with different scenario, they give it different identifier. Figure 5 present an example of importation. The syntax is divide in three part: the keyword "import", the path to existing micro-model, and the identifier, to be used, followed the keyword "as".

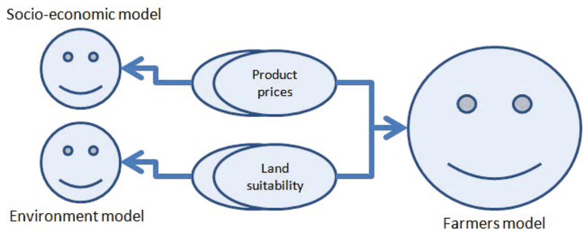

Fig. 4. An example with three models used for coupling approaches

```
import "marketProduct.gaml" as myMarket
import "SeaLevel.gaml" as mySea
import "environmentChange.gaml" as myEnv
```

Fig. 5. Importing model as micro-species

Instantiation. This phase will instantiate agent of micro-model. Modeler can use identifier that they declare in importation phase, to instantiate micro-model with "create" statement. Thus , we have provided to reuse one model many times with "identifier", modeler can initialize the micro-model with different input values as parameters. Figure 6 demonstrate syntax of the instantiation the micro-models with default value of parameters, nothing was declared in statement: keyword create, micro-model's identifier.

```
init {
        create myMarket.marketgrow;
        create mySea.SaltIntrusion;
        create myEnv.envChange;
```

Fig. 6. Instantiate agents of micro-species

Execution. Thanks to multi-level modeling in GAMA [16] and our coupling approach, the execution of micro-model carried out by asking micro-model's agent to do step by step of simulation. The syntax is simply semantic as natural language: "ask" micro-model's identifier do step (see Figure 7). Beside, modelers can access all behaviors, attributes of micro-models and do data-exchange between them.

```
ask myMarket.marketgrow
{
    do _step_;
    myself.price_rice <-  priceRice;
    myself.price_shrimp <- priceShrimp;
    myself.price_coconut <- priceCoco;
}


ask mySea.SaltIntrusion
{
    loop times: 10
    {
        do _step_;
    }
    myself.envOut <- outParcel;
}
```

Fig. 7. Ask agents of micro-species to simulate and exchange data between models

4 Experiments

4.1 Objectives

This part will show the experimentation of our coupling approaches framework by applying the coupling model for Land use change modeling in Thanh Phu district, Ben Tre province. We have 3 scenarios for testing as the reasons of land use change: (1) The farmer changed their land use type following the others based on the increasing of price product; (2) The natural condition changed by the new dike build or operation of the sluice gates to control the salted water effect to decision of farmer; (3) Combine two condition : product prices and salt intrusion. The purpose of the co-models is to show the progressive that how we have solve issues of : Spatial - temporal scales, the coupling entities between models, and the presentation of organization co-models.

4.2 Data Used

The land unit map of Thanh Phu district have done by GIS analysis method UNION the single layers: soil, saline water and flood depth layer. The land unit map are used for determining the properties of land parcel on it. Each farmer have a parcel, each parcel based on a land unit that contains soils type, a land use type, saline level, flood duration and flood depth.

Land unit of Thanh Phu district (Source: My N T H, 2012) analyzing the Land Suitability of the land units for six popular land use types of the district as the 8. The levels of land suitability measure the capacity of the land unit for each land use type: S1 = 100.

The three scenarios use the following data structure: it contains the land use type, the area, salt level and land unit type. Land use type is the current type in agriculture of farmers, it can be Annual-crops, Aquaculture, Perennial-fruit, Perennial industrial crop, Rice, Rice Shrimp, 2 Rice 1 Annual-crops. The area of each parcel is in square meter units. Salt level present the level of salt intrusion, begin from 2/1000 to the highest 9/1000.

Id	Name	Type	Type name	Length	Precision
0	stt	double	Real	20	0
1	land_use	QString	String	30	0
2	landuse_vn	QString	String	30	0
3	landuse_en	QString	String	25	0
4	landuse201	int	Integer	6	0
5	landuse200	QString	String	30	0
6	lu_code	int	Integer	6	0
7	area	double	Real	20	1
8	saline	int	Integer	6	0
9	DVDD	int	Integer	4	0
10	stt_2	int	Integer	4	0
11	CODE	int	Integer	4	0
12	MOTA	QString	String	100	0

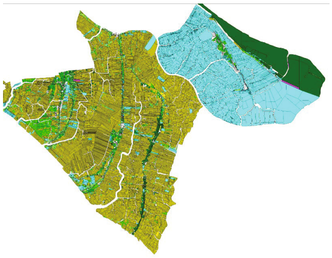

Fig. 8. Input data of Land use model (left) and real map in 2010 (right)

4.3 Scenarios 1 : Coupling with Economic Model

The first scenario, farmers take decisions depend on price of products. The price come from a micro-model which simulate the price change of agriculture product from 2005 to 2010, the data is take from real market and modeled in a mathematical function, ffigure 9 show the value from this model.

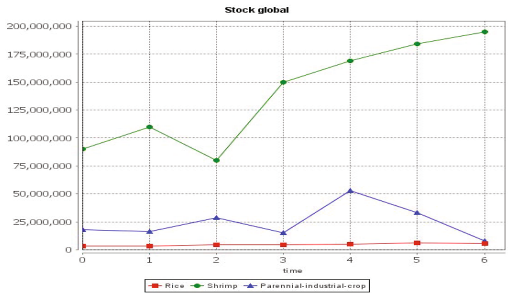

Fig. 9. Market product price in VND simulated from 2005 to 2010

The farmers take decision the best price product that their neighbors have, to change their next land use plan. This scenario reach to show the capability of coupling between mathematical model and agent-based model. At each simulation step, farmers ask economic model to get the price of all products types in that year, then they look in their neighbors to compared the highest benefit to decide the next types of products in next simulation.

Figure 10 show the reality that the product price did not change too much, so the decision of farmers are keeping in their current type of land-use, until the product price have a big change for their benefits.

4.4 Scenarios 2 : Coupling with Environment Model

In this scenario, we couple two models, one define the agriculture activities of farmers on their land unit, other model simulate the salt intrusion where the

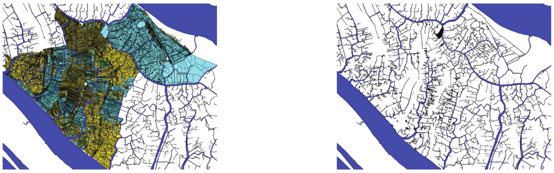

Fig. 10. Simulation results when coupling farmer's land-use model with market product model

salt level in the river diffuse to land unit in dry season, and inverse the direction of diffusion in rain season. Then, at each simulation step, farmers look at environment especially soil and water properties effected by salt intrusion. If the salt level of the parcel is too high (over 0.8/1000 units) farmer could not do any other agriculture activities except the aquaculture. If salt level is lower, they can make choice of rice shrimp or other types suitable with salt level. We see the changes in result (Figure 10 black part on the right) compared with the current state (Figure 8 right part).

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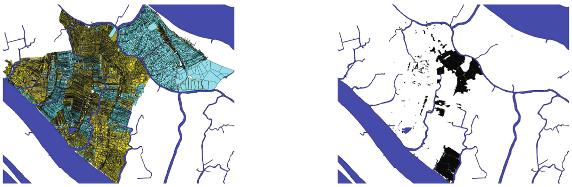

Fig. 11. Simulation Results when coupling farmer's land-use model with environment model (salt intrusion)

After simulation, the state of land use change show the effect of salt intrusion in two area (black color). These two one is nearest river and take too much salt from river in dry season. The farmers chose to change from rice type to rice shrimp type, which is adopt by higher salt level.

4.5 Scenarios 3 : Coupling with Environment and Economic Model

In the last scenario, we decide to combine these three models together as in Figure 4, to see the effects on the fly of the farmers. They consider both conditions on economic and environment changes beside their desire to maximize income but minimize pollution and risk financial. At each simulation step, the price product and salt intrusion modify attribute land use type, salt level of parcels in progress of changes the agriculture activities. Firstly, if last changed of land use type to Perennial tree, farmer have to wait at least 4 years to other LUT; Secondly, farmers do the Perennial or fruit near their house, their parcel have to touch the river; Thirdly, They can not do rice, vegetable or fruit inside the people how are doing shrimp because he dont have fresh water, inversely they can not do the shrimp inside the rice or fruit. Lastly, the Shrimp type have to touch river, channel or other shrimp.

Figure 12 show the result which have many change compared with current state in 2010, it demonstrate the strong effect when we coupling environment with price product into the land use change.

Fig. 12. Simulation results in case of coupling both environment and socio-economic model with farmer's land-use

4.6 Verify Results

The simulation of each scenario run with 5 steps, corresponding with 5 years from 2005 to 2010, and it repeat 5 times to take the average values. We take the total area of each type of agriculture in 2010 and make a compare chart as in Figure 13. In this current research we just review on this chart between real data and simulation results.

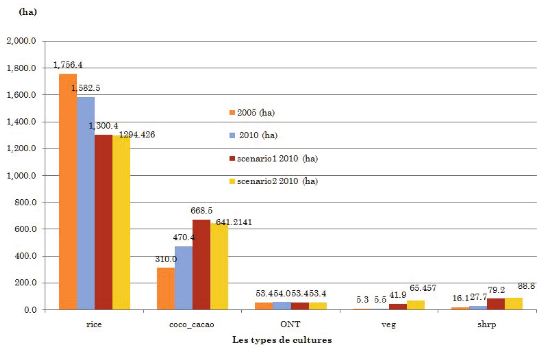

Fig. 13. Total area of products in simulated result comparing with real data in 2010

Current validation cannot compare these consecutive parcel or definitely position, the neighbors was just moving a little bit which are considered as no changed... Improvement in our future works will be the applying fuzzy kappa algorithm [15].

5 Conclusion

This paper has proposed a coupling methodology in multi-agent based modeling, and implemented it to platform GAMA. With this implementation, modeler can easily reuse multi exists models. The current infrastructure allows developers to integrate diversity type of model (multi-agent, mathematical) and also diversity platforms which is in experimental phase supporting R language. In the next research, we will made the validation of coupling model by exploring number of parcels and the distant of right parcel to the simulated parcel.

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